PHENIX measurement of jet properties and their modification in heavy-ion collisions

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Partonic degree of freedom in HI

Highlights from RHIC AuAu program:

- high-p_T particle yield suppression – jet quenching
- disappearance of the back-to-back jet in central collisions
- exceedingly large azimuthal anisotropy v_2

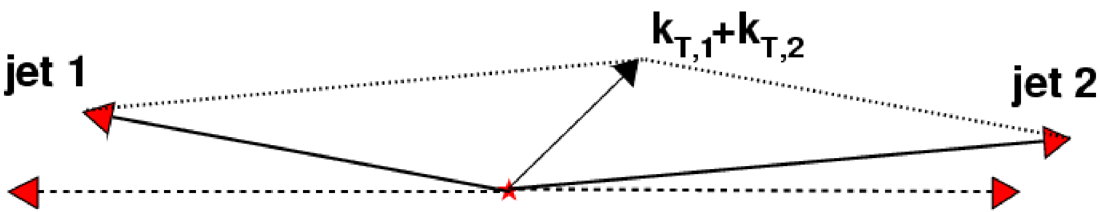
Detailed analysis of parton/jet properties like:

- shape of the fragmentation $D(z)$ and parton distribution function $f_q(p_{Tq})$
- parton transverse momentum $\langle k_T^2 \rangle$

and their modification is vital for understanding of the mechanism of parton interaction with QCD medium formed at RHIC

Hard scattering

Hard scattering in transverse plane



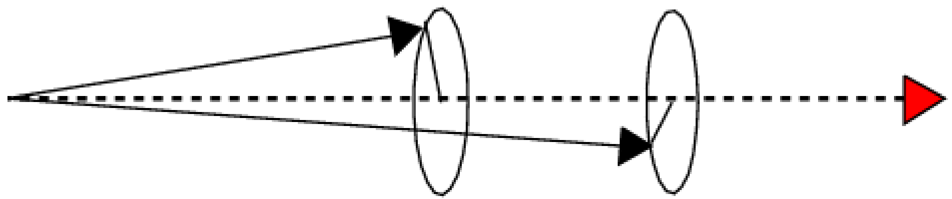
Point-like partons $\Rightarrow$ elastic scattering $\quad \vec{p}_{T,jet1} + \vec{p}_{T,jet2} = \vec{0}$

Partons have intrinsic transverse momentum $\boldsymbol{k_T}$ $\quad \vec{p}_{T,jet1} + \vec{p}_{T,jet2} = \vec{k}_{T,1} + \vec{k}_{T,2}$

Jet Fragmentation (width of the jet cone)

Partons have to materialize (fragment) in colorless world

$\vec{j}_T$ = jet fragmentation transverse momentum



j_T and k_T are 2D vectors. We measure the mean value of its projection into the transverse plane $\langle|j_{Ty}|\rangle$ and $\langle|k_{Ty}|\rangle$.

$$\langle| k_{Ty} |\rangle = \sqrt{\frac{2}{\pi}}\sqrt{\langle k^2{}_T\rangle}$$

$\langle|j_{Ty}|\rangle$ is an important jet parameter. It's constant value independent on fragment's p_T is characteristic of jet fragmentation (j_T-scaling).

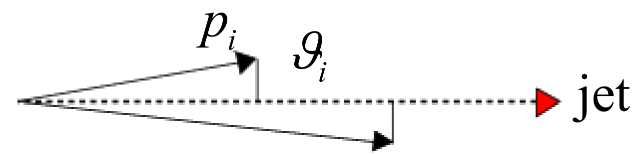
$\langle|k_{Ty}|\rangle$ (intrinsic + NLO radiative corrections) carries the information on the parton interaction with QCD medium.

$$\langle k_\perp{}^2\rangle_{AA} = \langle k_\perp{}^2\rangle_{vac} + \langle k_\perp{}^2\rangle_{IS\ nucl} + \langle k_\perp{}^2\rangle_{FS\ nucl}$$

p+p p+A A+A

Fragmentation Function (distribution of parton momentum among fragments)

In Principle



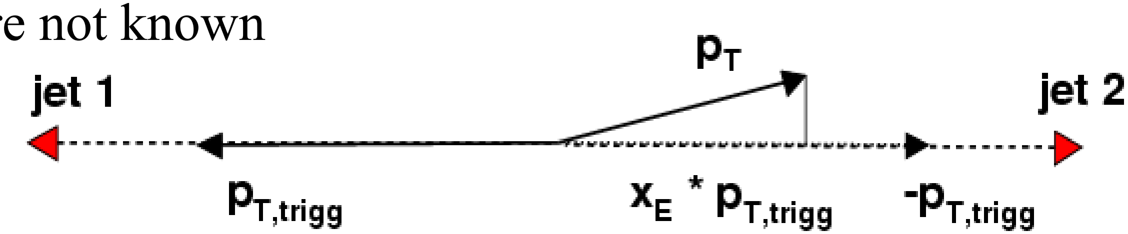
$$\vec{p}_{parton} = \sum_i \vec{p}_i \qquad |\vec{p}_{parton}| = \sum_i |\vec{p}_i| \cos(\vartheta_i)$$

$$z_i = \frac{|\vec{p}_i| \cos(\vartheta_i)}{|\vec{p}_{parton}|} \qquad \sum_i z_i = 1$$

$$\boxed{\text{Fragmentation function} \quad D(z) \propto e^{-z/\langle z \rangle}}$$

In Practice parton momenta are not known

$$x_E = -\frac{\vec{p}_T \cdot \vec{p}_{Ttrigg}}{|\vec{p}_{Ttrigg}|^2}$$



$$x_E z_{trigg} = \frac{p_T \cos(\Delta\varphi)}{p_{parton}} = z$$

$\Rightarrow$ Simple relation $\boxed{\langle z \rangle = \langle x_E \rangle \langle z_{trigg} \rangle}$

x_E in pp collisions

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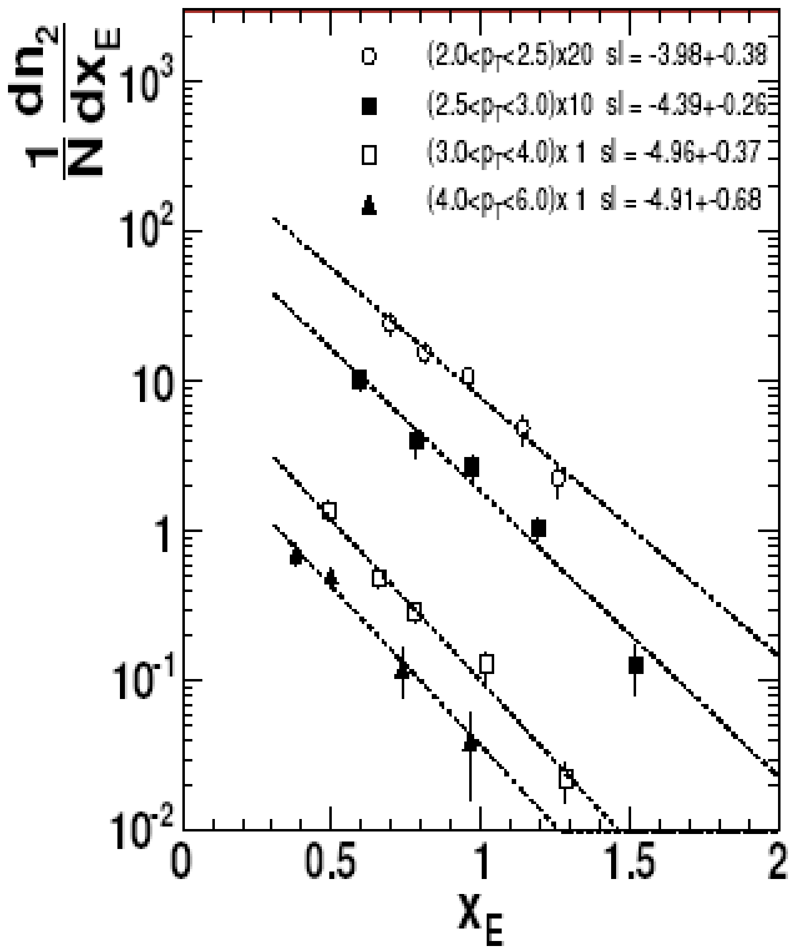
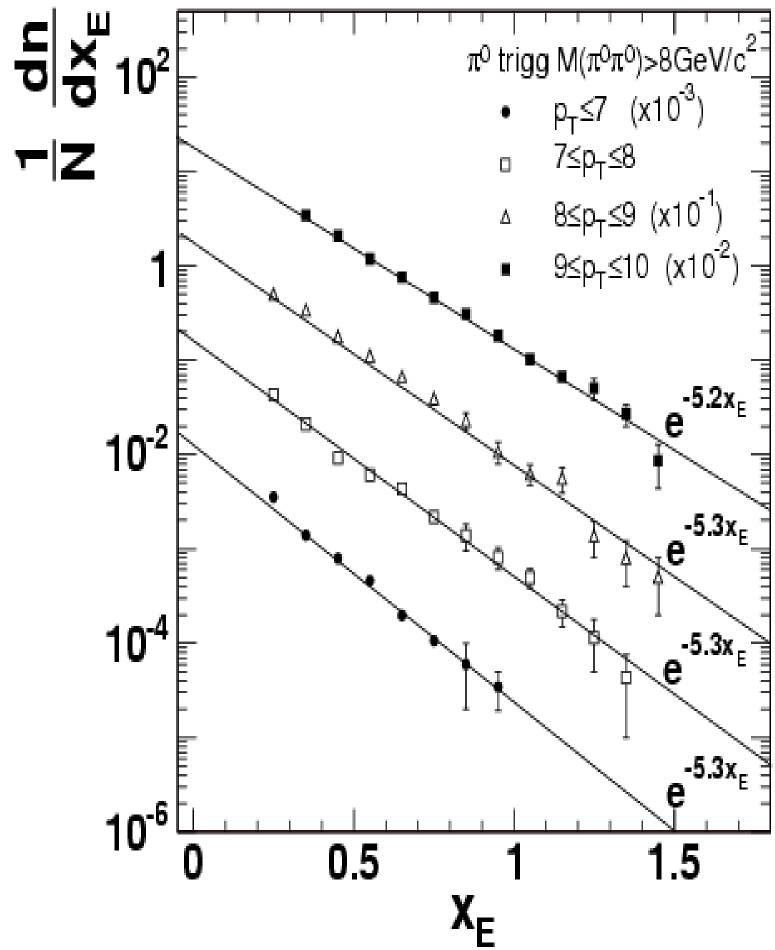


$1/\langle x_E \rangle \approx -4$ to -5

CCOR (ISR) $\sqrt{s}$ = 63 GeV

see A.L.S. Angelis, Nucl Phys B209 (1982)



$1/\langle x_E \rangle \approx -5.3$

$\langle z \rangle$ extracted from pp data

We measured x_E and

$$\langle z \rangle = \langle x_E \rangle \langle z_{trigg} \rangle$$

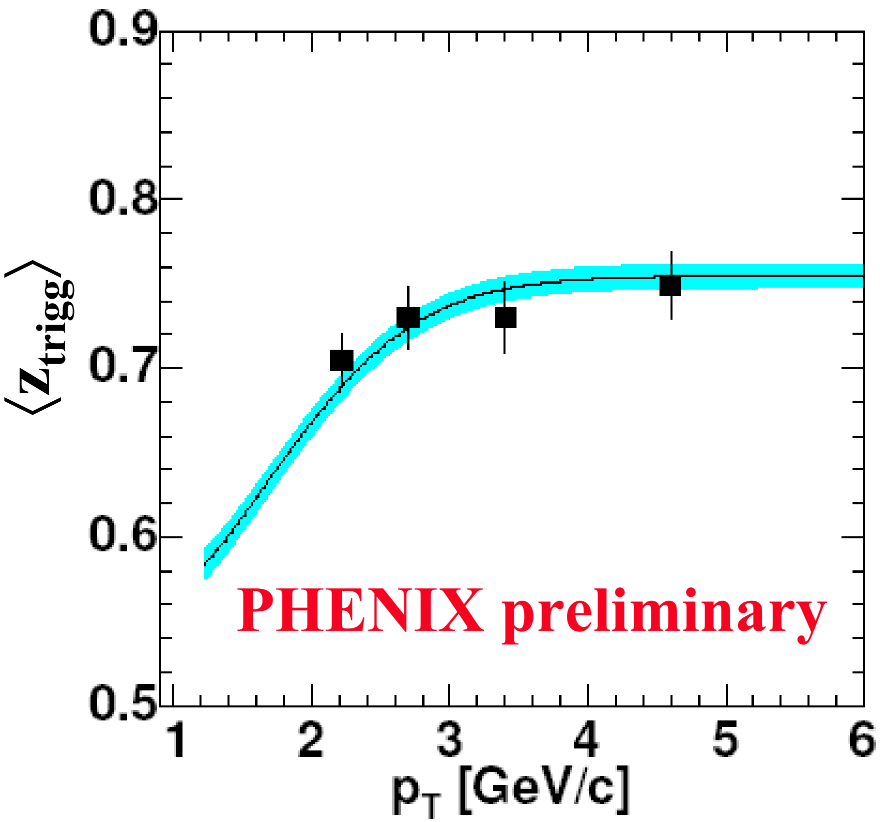
$x_{Ttrigg}=2.p_{Ttrigg}/\sqrt{s}$

$$\langle z_{trigg} \rangle \propto \int_{x_{Ttrigg}}^{1} z \cdot e^{-z/\langle z \rangle} f_q(p_T / z) \cdot z^{-2} dz$$

Only one unknown variable $\langle z \rangle$ ⇒ iterative solution

FFn $D(z)$

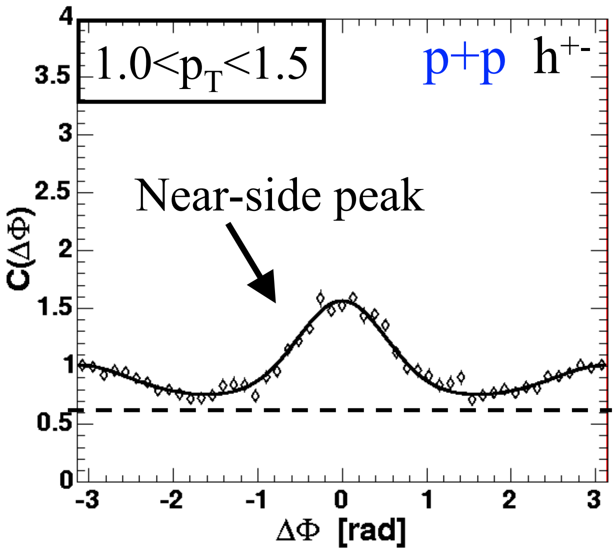
final state parton distrib. extracted from PHENIX $p+p \rightarrow \pi^0+X$

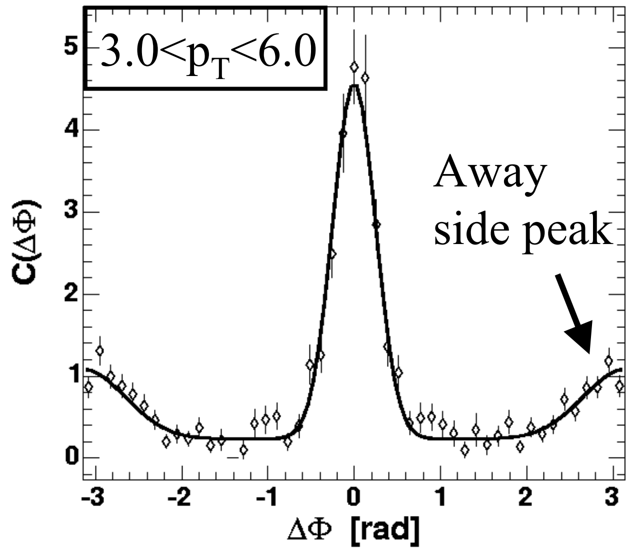


Slope of the fragmentation function in p+p collisions at $\sqrt{s}$=200 GeV

$$\frac{1}{\langle z \rangle} = 6.16 \pm 0.32$$

pp and dAu correlation functions



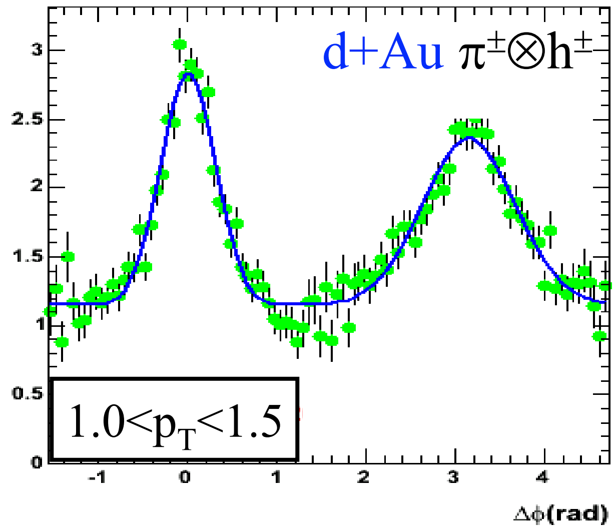


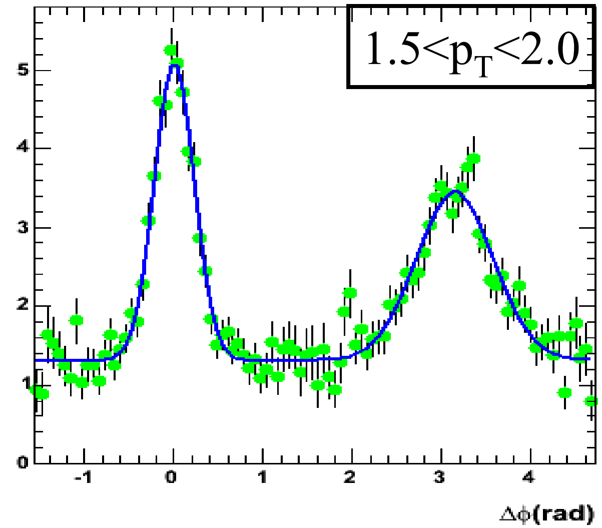
Fixed correlation:

both p_{Ttrigg} and p_{Tassoc} are in the same range

Assorted correlation:

p_{Ttrigg} and p_{Tassoc} different





$5.0 < p_{Ttrigg} < 16.0$ GeV/c

Jet function assumed to be Gaussian

$$C_{ij}(\Delta\phi) = norm \cdot \frac{dN^{real}_{ij}}{d\Delta\phi_{ij}} \Big/ \frac{dN^{mixed}_{ij}}{d\Delta\phi_{ij}}$$

→ Fit = const + Gauss(0)+Gauss(±π)

σ_N, σ_A , $\langle|j_{Ty}|\rangle$, $\langle|k_{Ty}|\rangle$ relations

Knowing σ_N and σ_A it is straightforward to extract $\langle|j_{Ty}|\rangle$ and $\langle z_{trigg}\rangle\langle|k_{Ty}|\rangle$

In the high-p_T limit ($p_T \gg \langle|j_{Ty}|\rangle$ and $p_T \gg \langle|k_{Ty}|\rangle$)

$$\langle|j_{\perp y}|\rangle = \langle p_\perp \rangle \sin\frac{\sigma_N}{\sqrt{\pi}}$$

$$\langle|k_{Ty}|\rangle \approx \langle p_T \rangle \sqrt{\sigma_A^2 - \sigma_N^2}$$

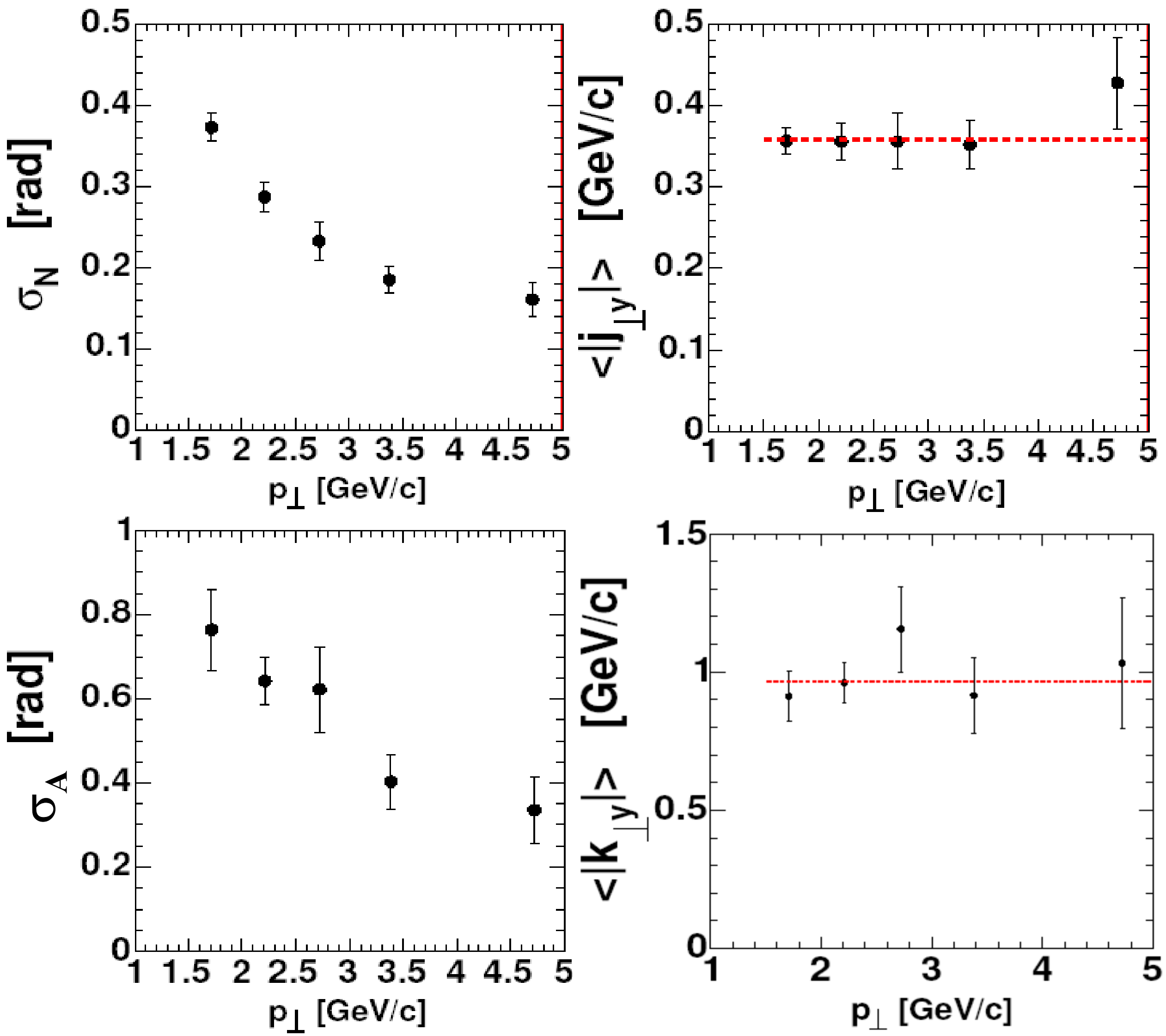
However, inspired by Feynman, Field, Fox and Tannenbaum (see *Phys. Lett. 97B (1980) 163*) we derived more accurate equation

$$\langle z_{trigg}\rangle\langle|k_{Ty}|\rangle = \frac{\langle p_T\rangle}{\sqrt{2}\,x_h}\sqrt{\sin^2\sqrt{\frac{2}{\pi}}\sigma_A - (1+x_h^2)\sin^2\frac{\sigma_N}{\sqrt{\pi}}}$$

$x_h = p_{T,assoc} / p_{T,trigg}$

See poster P07, P. Constantin

$\sigma_N, \sigma_A \rightarrow \langle|j_{Ty}|\rangle, \langle|k_{Ty}|\rangle$ in pp data



$$\langle k_\perp^2 \rangle_{pp} = \langle k_\perp^2 \rangle_{vac}$$

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$\langle|j_{Ty}|\rangle = 359 \pm 11$ MeV/c

$\langle|k_{Ty}|\rangle = 964 \pm 49$ MeV/c

Both $\langle|j_{Ty}|\rangle$ and $\langle|k_{Ty}|\rangle$ in very good agreement with previous measurements:

PLB97 (1980)163

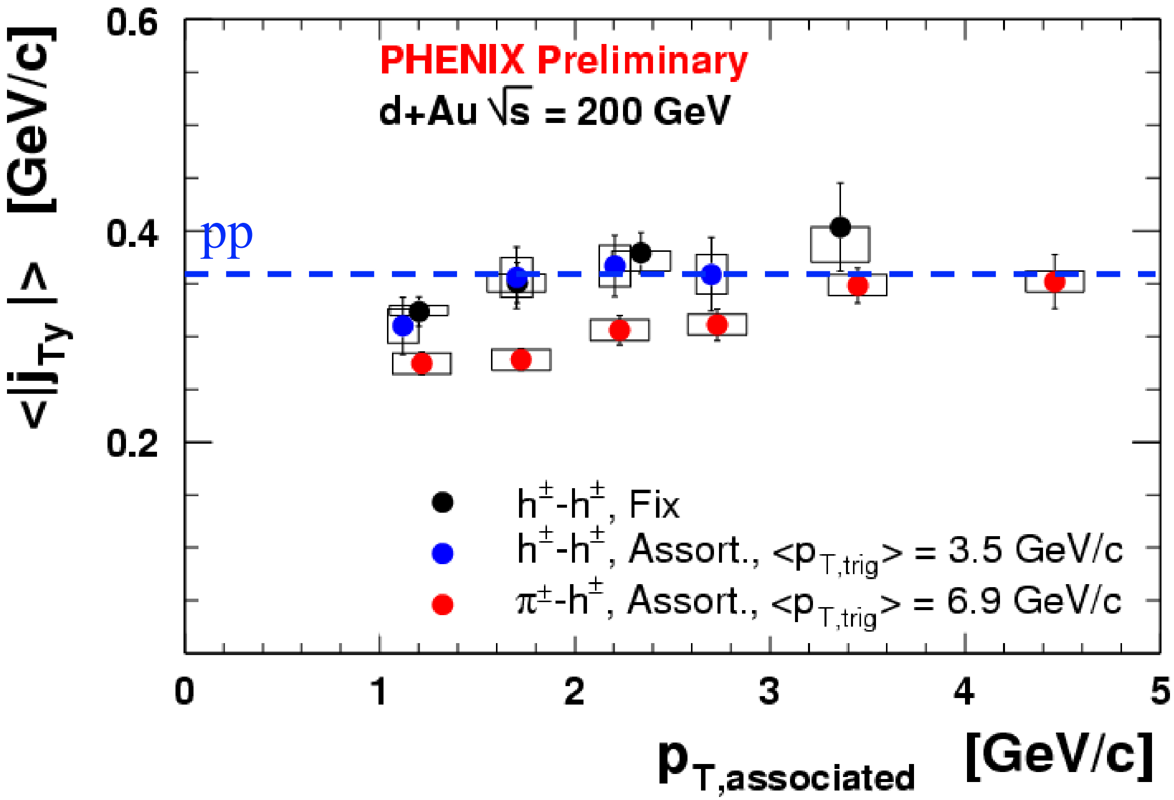
PRD 59 (1999) 074007

From pp to dAu

$$\langle k_\perp^{\;2} \rangle_{\mathrm{dAu}} = \langle k_\perp^{\;2} \rangle_{\mathrm{vac}} + \langle k_\perp^{\;2} \rangle_{\mathrm{IS\ nucl}}$$

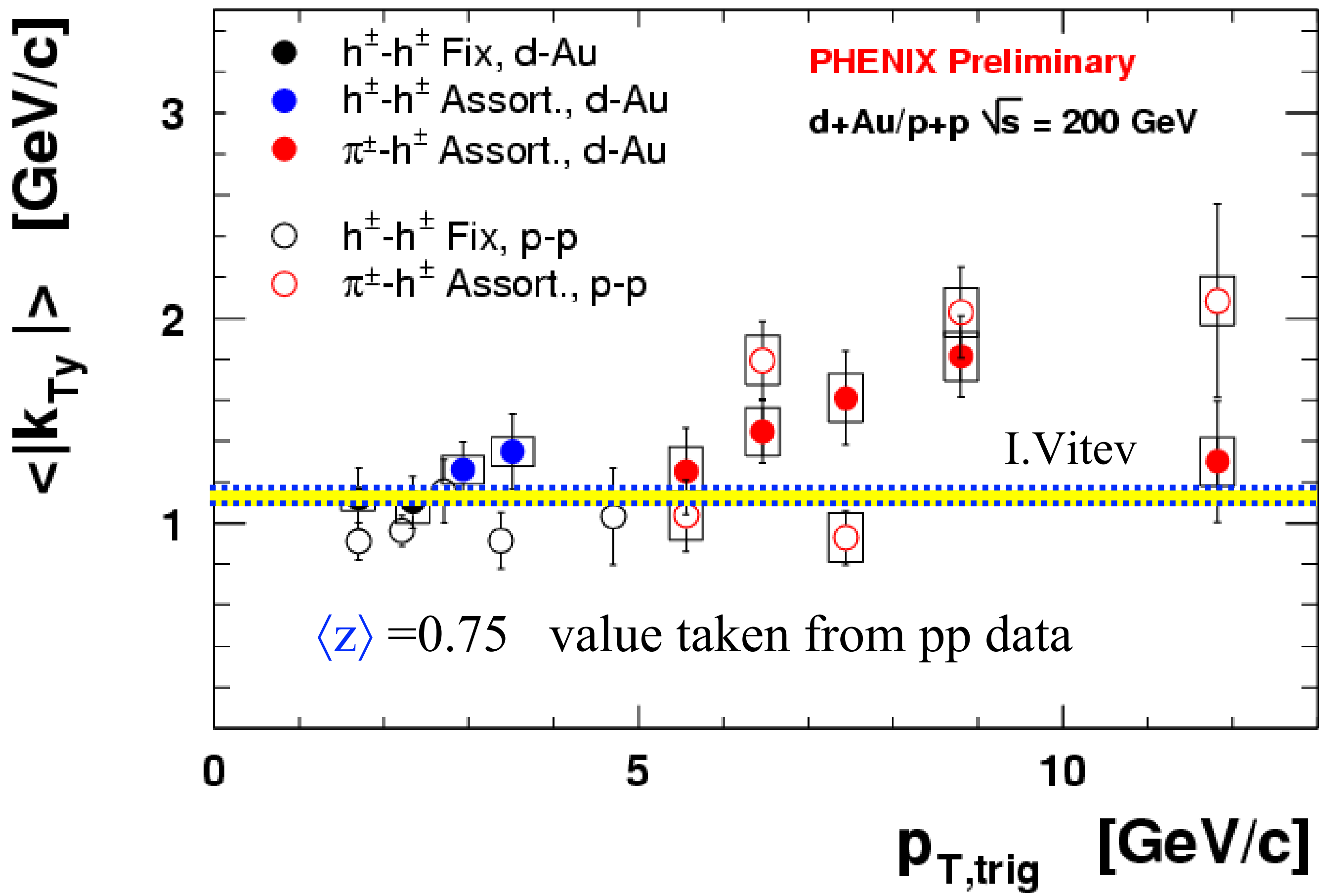
$\langle |k_{Ty}| \rangle$ carries the information on the parton interaction with cold nuclear matter.

$\langle |j_{Ty}| \rangle$ should be the same as in pp – systematic cross check



$\langle|k_{Ty}|\rangle$ from pp and dAu

$$\langle \Delta \mathbf{k}_T^2 \rangle_{IS} = \mu^2/\lambda_{eff} \langle L \rangle_{IS}$$ I.Vitev nucl-th/0306039



No significant k_T-broadening seen in dAu data

See poster P03 J. Jia and P05 N. Grau

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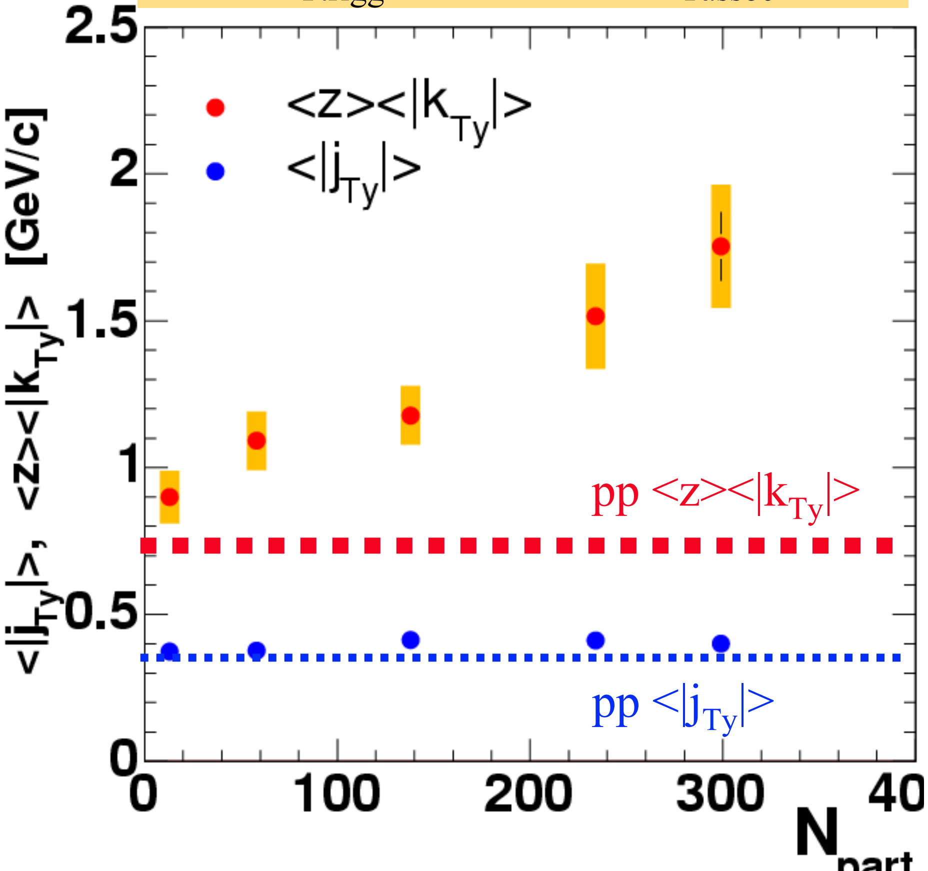
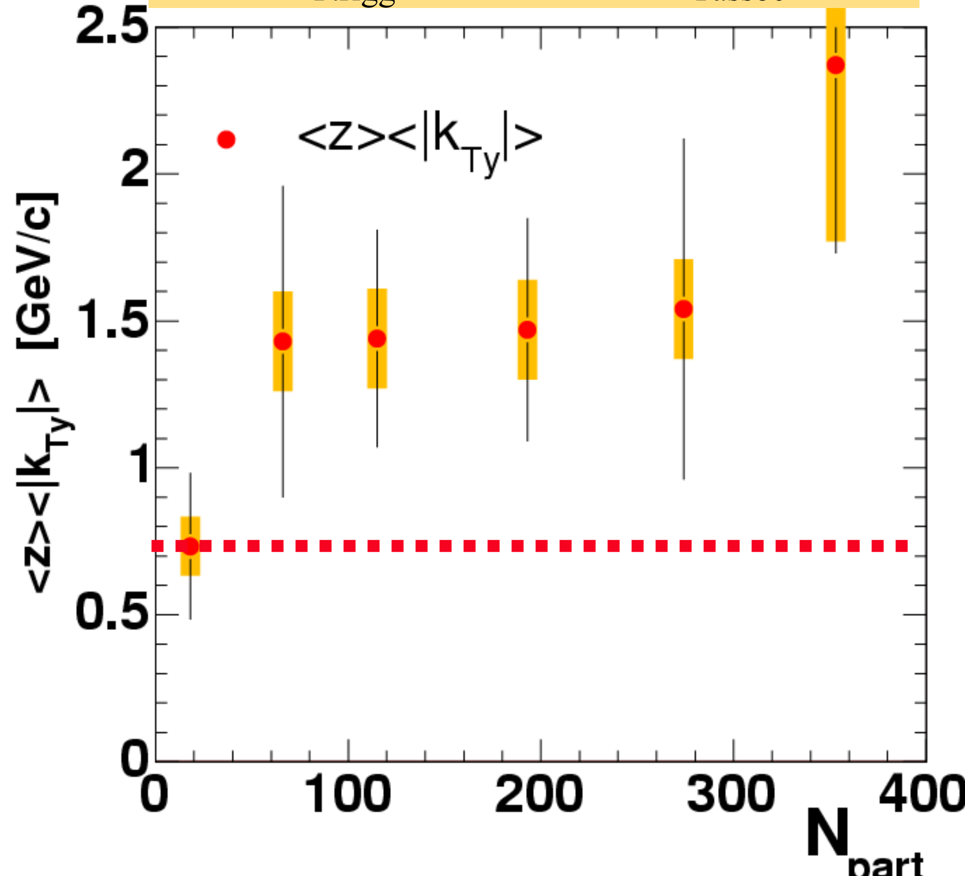
AuAu $\langle|j_{Ty}|\rangle$ and $\langle z\rangle\langle|k_{Ty}|\rangle$ from CF

$$\langle k_\perp^{\;2}\rangle_{AA} = \langle k_\perp^{\;2}\rangle_{vac} + \langle k_\perp^{\;2}\rangle_{IS\ nucl} + \langle k_\perp^{\;2}\rangle_{FS\ nucl}$$

$(2.5<p_{Ttrigg}<4.0)\otimes(1.0<p_{Tassoc}<2.5)$

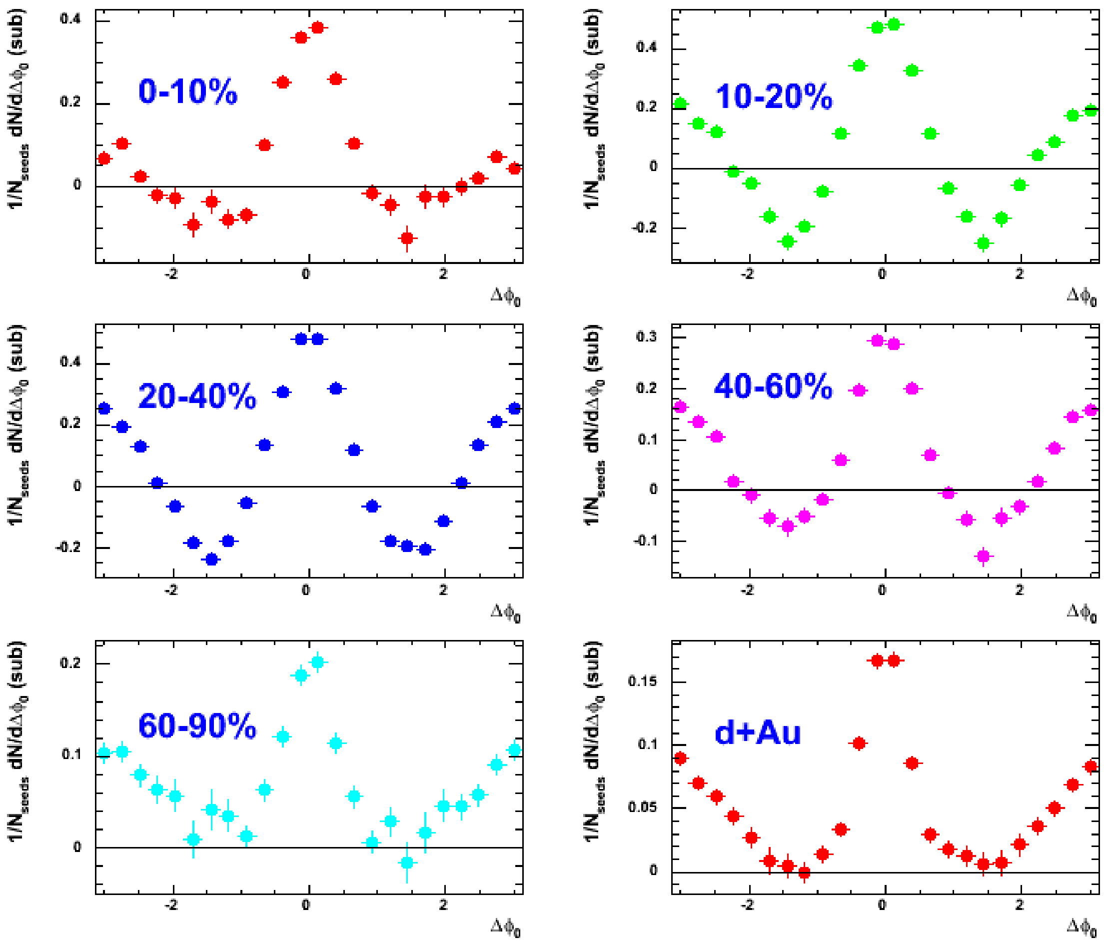


$(3.0<p_{Ttrigg}<5.0)\otimes(1.5<p_{Tassoc}<3.0)$

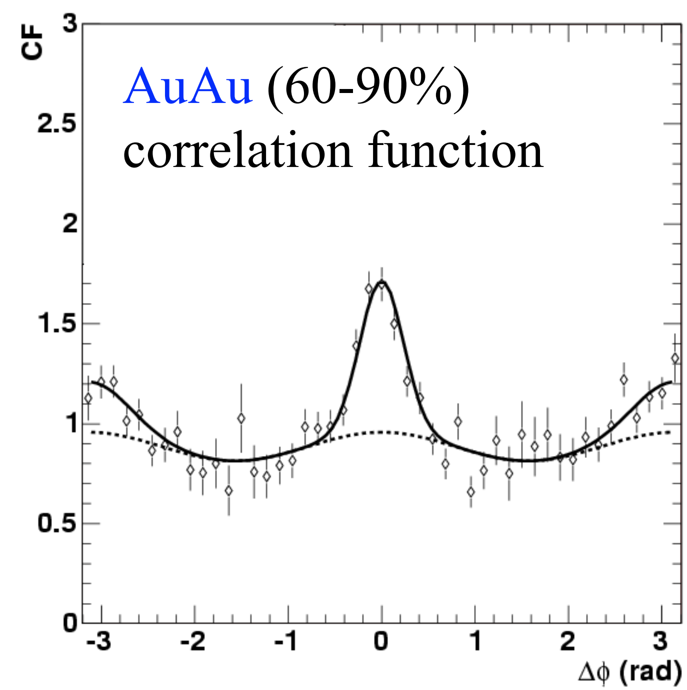


There seems to be significant broadening of the away-side correlation peak which persists also at somewhat higher p_T range.

AuAu yield



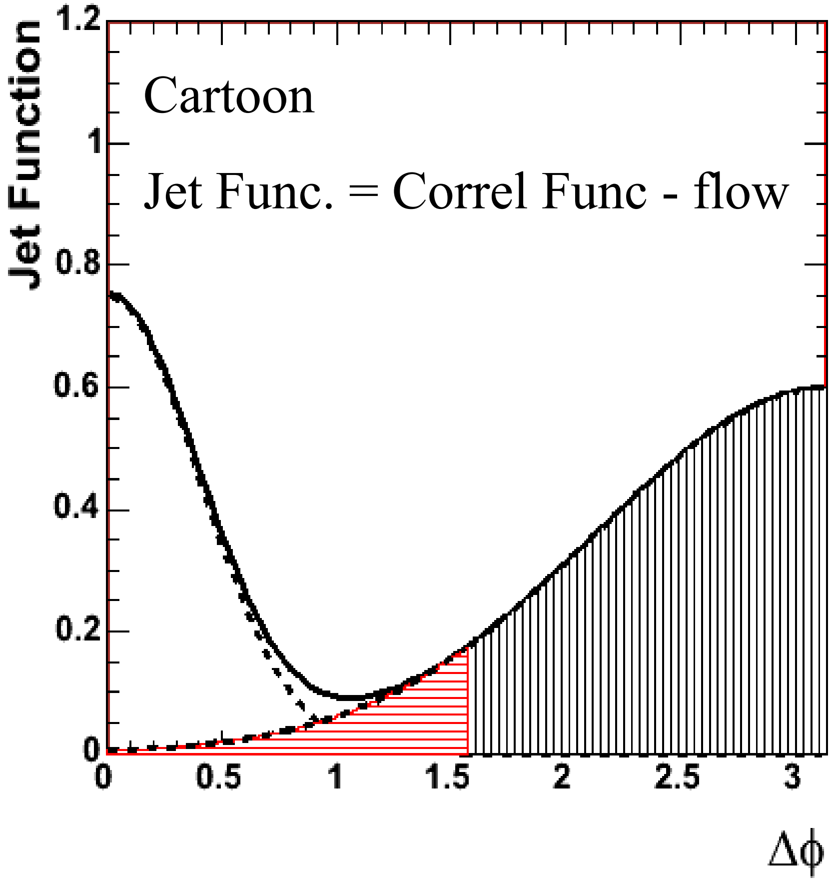
Subtracted $dN/d\Delta\varphi$ integrating from 0-90, 90-180 to remove the v_2 component.

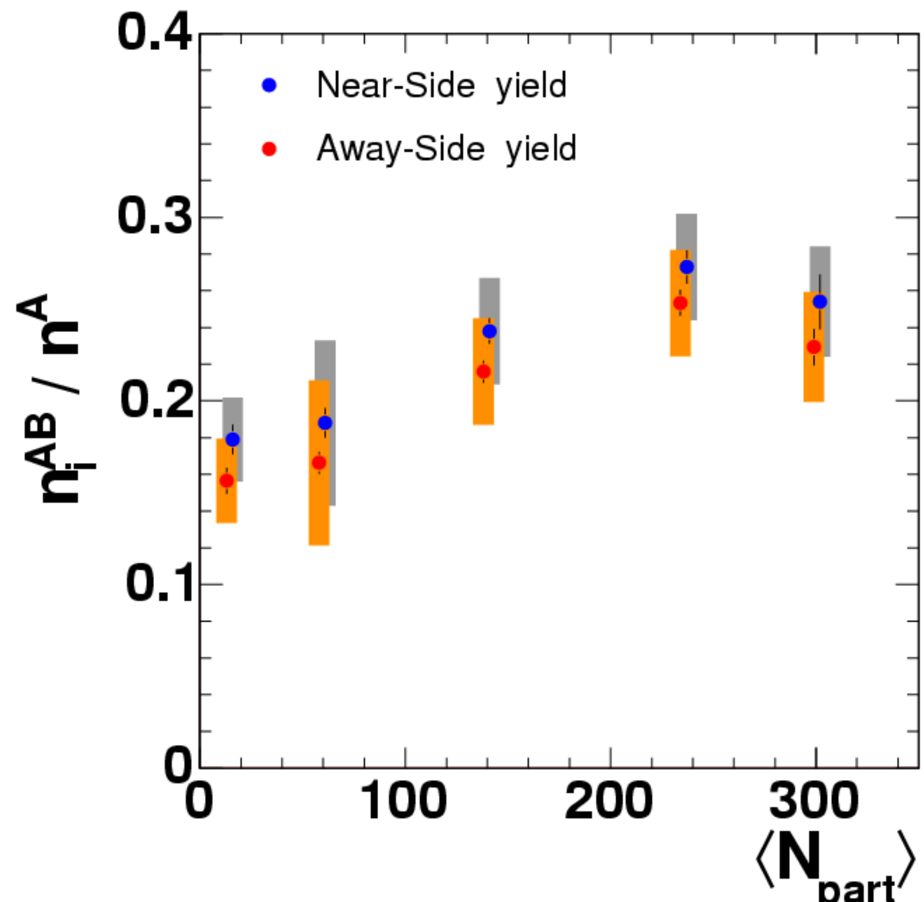


$(2.5<p_{Ttrigg}<4.0)\otimes(1.0<p_{Tassoc}<2.5)$ GeV/c

AuAu associated yields

$(2.5<p_{T\,trigg}<4.0)\otimes(1.0<p_{T\,assoc}<2.5)$ GeV/c





Note p_T is rather low; associated particle yields increase with centrality

See poster C10, N.N. Ajitanand

Summary and conclusions

Jet production and fragmentation in pp, dAu and AuAu collisions:

- the slope of the fragmentation function in pp
- σ_N , σ_A , $\langle|j_{Ty}|\rangle$ and $\langle|k_{Ty}|\rangle$ in pp, dAu, AuAu
- Variation of the conditional yield of back-to-back particles with N_{part} in AuAu

We found:

- Good agreement of the jet properties in pp collisions with other experiments
- dAu j_T and k_T consistent with pp
- In AuAu significant k_T - broadening with centrality
- Yield of away side associated particles shows rising trend with N_{part}

Next step:

- map out this trend to explore whether this is a hint of jet-quenching balance
- Explore the AuAu fragmentation function

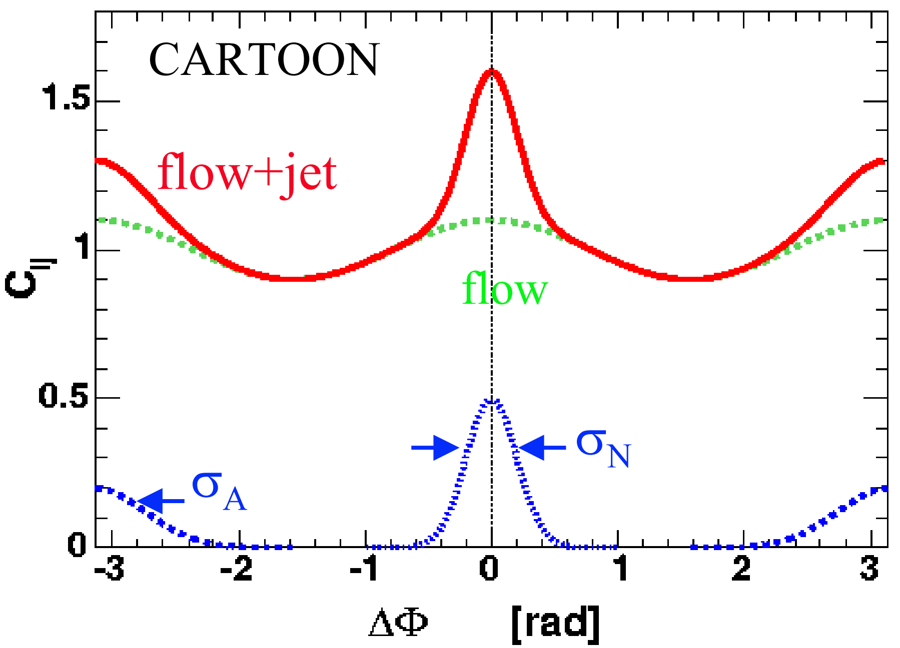
Backup slides

Method - azimuthal correlation function

Now we know the $\langle z \rangle$ - let us measure σ_N and σ_N.
Two particle azimuthal correlation function →

$$C_{ij}(\Delta\phi) = norm \cdot \frac{dN^{real}_{ij}}{d\Delta\phi_{ij}} \Big/ \frac{dN^{mixed}_{ij}}{d\Delta\phi_{ij}}$$

Unavoidable source of two particle correlations in HI – elliptic flow



"flow" pairs :

$$[1+2v_2^2 \cos(2\Delta\varphi)]$$

Intra-jet pairs angular width :

$$\sigma_N \to \langle |j_{Ty}| \rangle$$

Inter-jet pairs angular width :

$$\sigma_A \to \langle |j_{Ty}| \rangle \oplus \langle |k_{Ty}| \rangle$$

Comparison to outside world

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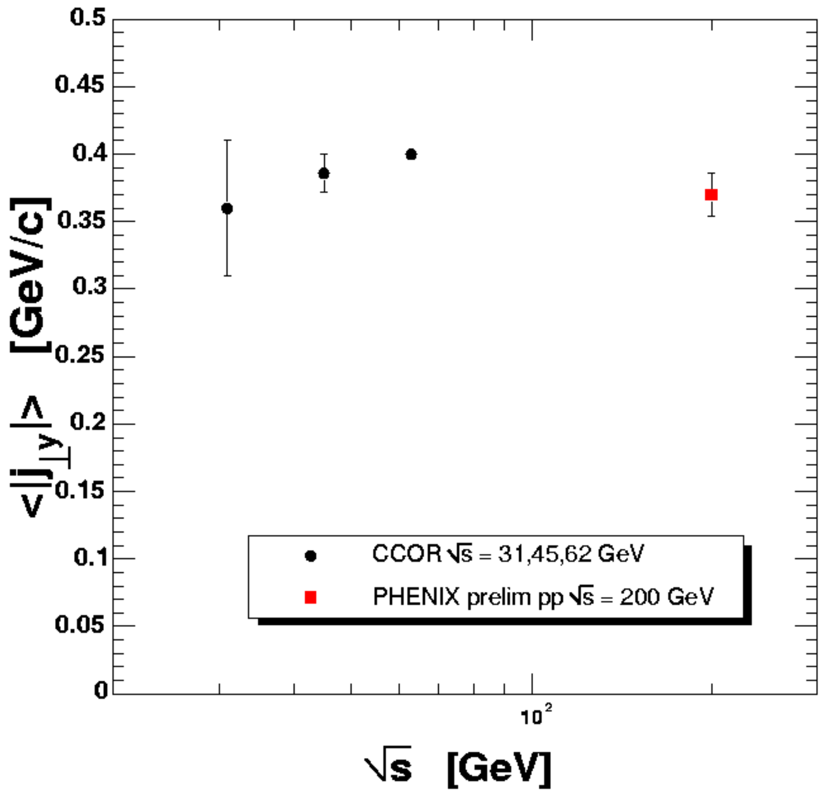
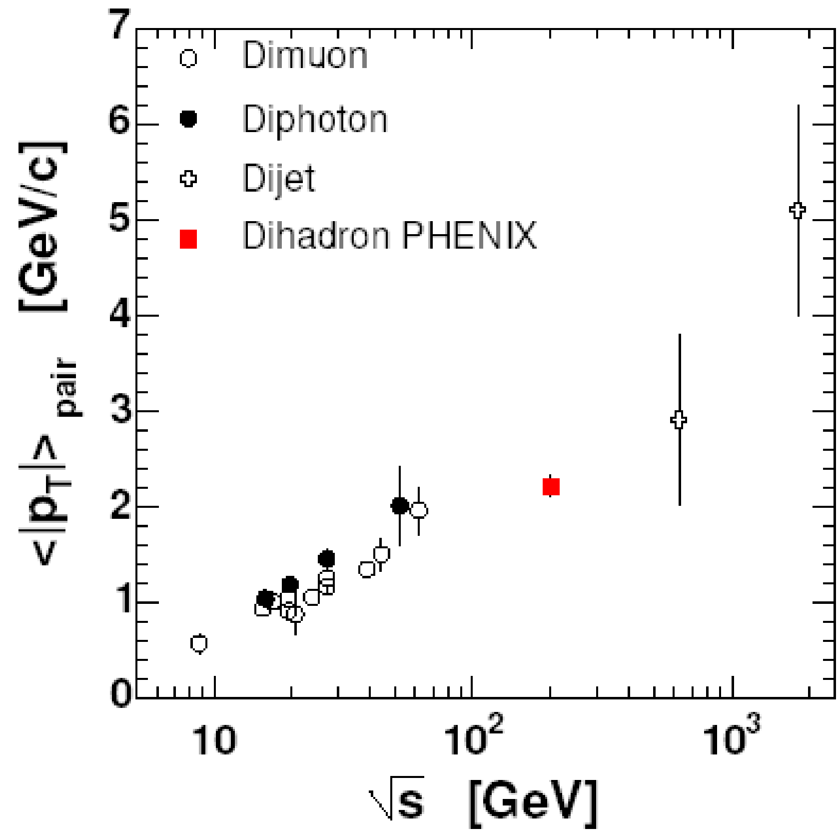
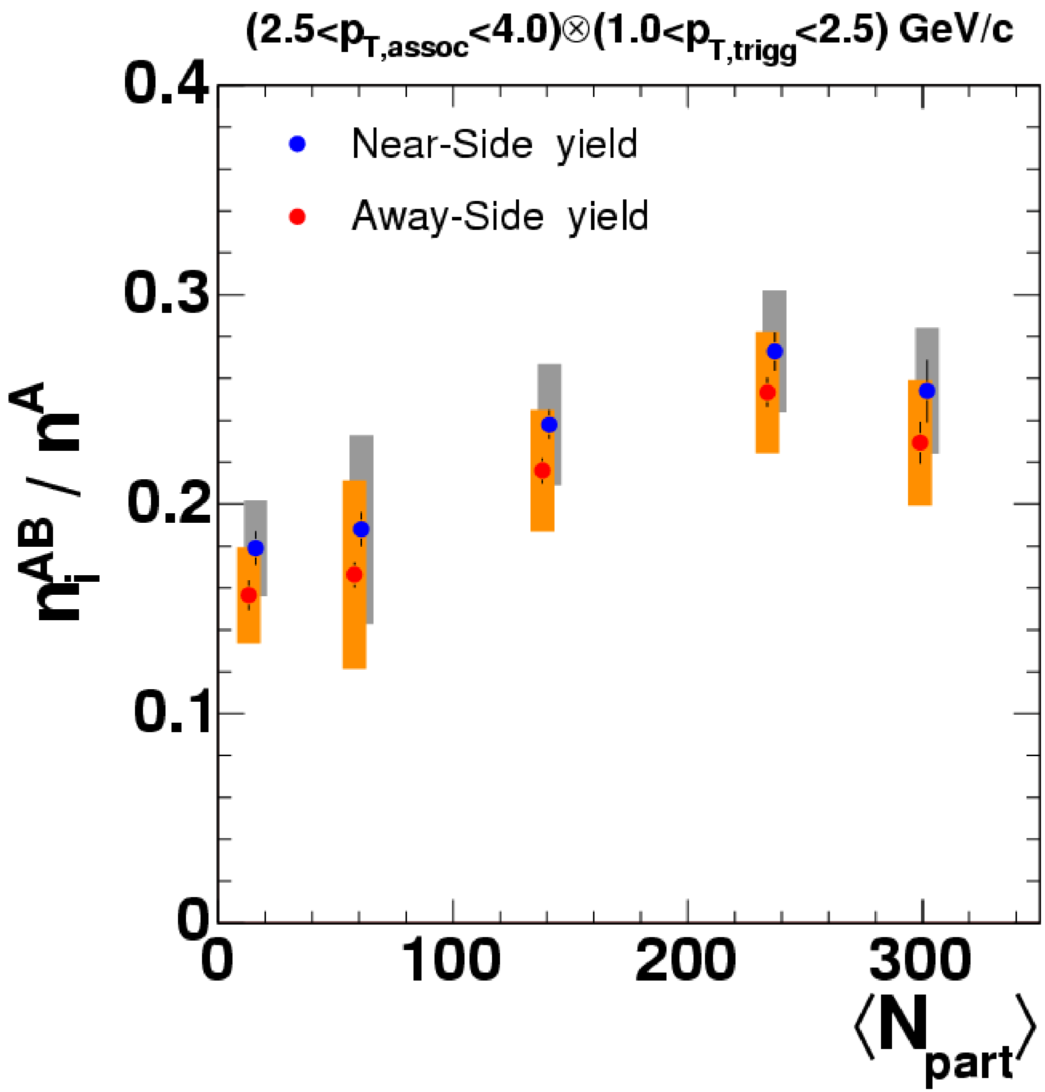




Add the legend – experiment names

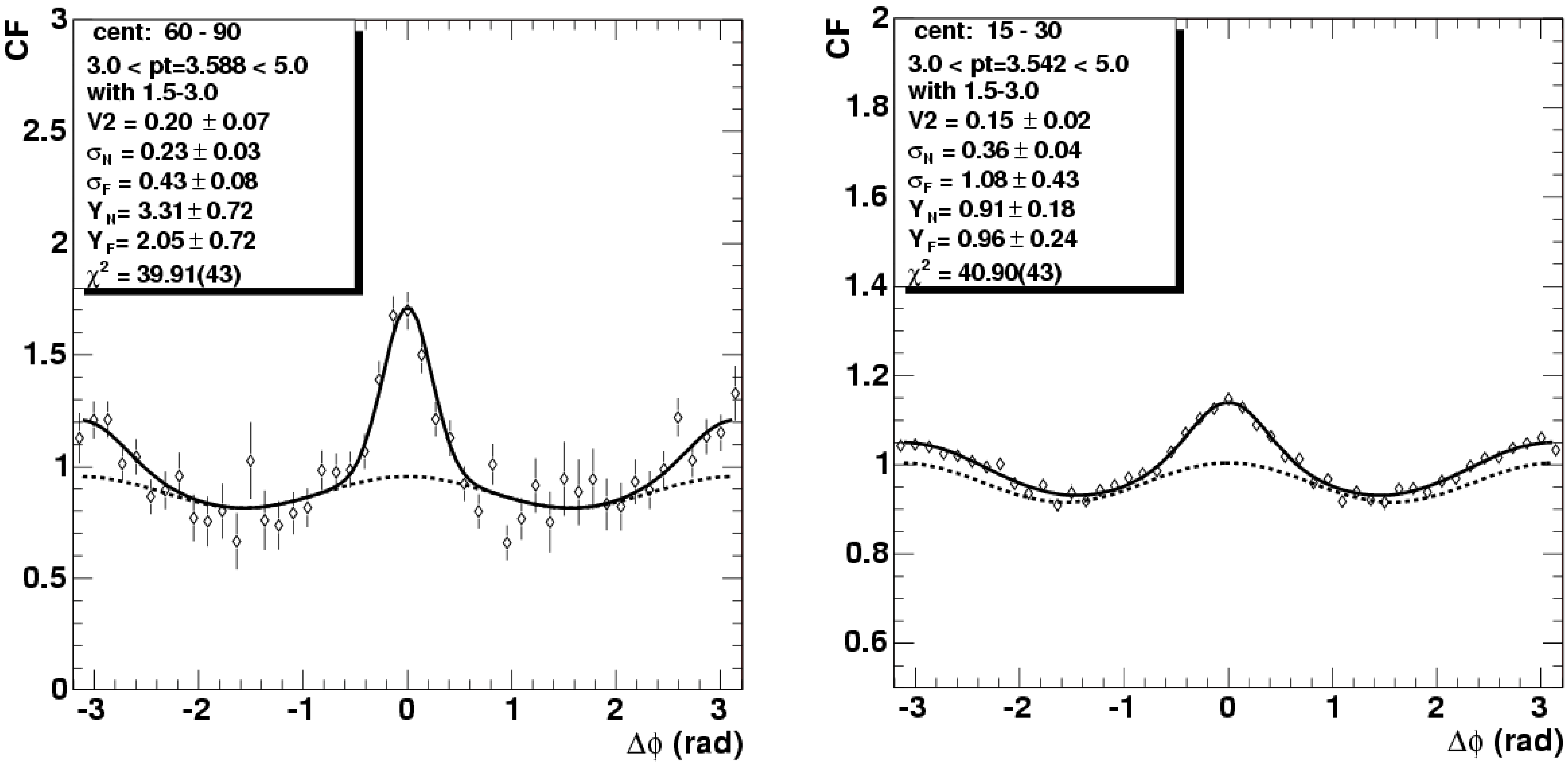
Larger markers and legends

yeilds



(2.5<p_T,assoc<4.0)⊗(1.0<p_T,trigg<2.5) GeV/c
Near-Side yield
Away-Side yield
0.4
0.3
0.2
0.1
0
0
100
200
300
n_i^{AB} / n^A
$\langle N_{part} \rangle$

CF's


CF
cent: 60 - 90
3.0 < pt=3.588 < 5.0
with 1.5-3.0
V2 = 0.20 ± 0.07
σN = 0.23 ± 0.03
σF = 0.43 ± 0.08
YN= 3.31 ± 0.72
YF= 2.05 ± 0.72
χ2 = 39.91(43)
Δφ (rad)
CF
cent: 15 - 30
3.0 < pt=3.542 < 5.0
with 1.5-3.0
V2 = 0.15 ± 0.02
σN = 0.36 ± 0.04
σF = 1.08 ± 0.43
YN= 0.91 ± 0.18
YF= 0.96 ± 0.24
χ2 = 40.90(43)
Δφ (rad)